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Accuracy of Objective Analysis at Stratospheric Levels

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ABSTRACT—The observed geopotential heights and temperatures (corrected for radiation effects) at the 100-, 50-, 30-, and 10-mb levels from most of the Northern Hemisphere radiosonde stations were compared with objectively analyzed heights and temperatures for February 1969. The 1-mo average root-mean-square (rms) height differences ranged from 51 m at 100 mb to 139 m at 10 mb. The rms temperature differences increased from 1.1°C at 100 mb to 2.9°C at 10 mb. Similar statistics are presented for North America and for different types of instruments.

1. INTRODUCTION

Gandin and Lugina (1969) have discussed the accuracy of the objective analysis systems utilized at various meteorological centers. Table I of their report indicated the root-mean-square (rms) differences between observed values of 500-mb height and values interpolated from objectively analyzed charts prepared by meteorological centers in eight countries. They concluded that at 500 mb an rms height difference of about 25 m was found on both the U.S.S.R. and United States National Meteorological Center (NMC) charts during 1964 and 1965, although the conclusion for NMC was apparently based on only three daily maps. This value is in good agreement with the 22-m value found by Bergthórsson and Döös (1955) in their study of 500-mb objective analyses. For other analysis centers, Gandin and Lugina reported rms differences up to 47 m for France.

This paper is concerned with evaluating the differences between reported values and objectively analyzed values of height and temperature on NMC charts for the 100-, 50-, 30-, and 10-mb levels. February 1969 was chosen for this study because reported temperature and height values were readily available on punch cards for this month. Also, during winter months the variability of the stratosphere is greater than in summer (Johnson and Gelman 1968), providing a wide range in reported and analyzed values of stratospheric parameters.

2. TECHNIQUE

All available 1200 GMT Northern Hemisphere radiosonde reports falling within the NMC grid (fig. 1) and with height or temperature information at any mandatory levels at or above 100 mb were compared with values given by objectively analyzed fields. At levels above 100 mb, various techniques are used to enlarge the ontime, onlevel data available for the field analyses. These techniques, discussed at length by Finger et al. (1965), include the use of reports offtime by as much as 12 hr before or after analysis time and also the use of offlevel data extrapolated upward from the termination level of the rawinsonde to the next mandatory level. The offtime data are used for the analysis but are not included in this study. The offlevel, ontime data are introduced into the analysis and are included in the 1200 GMT data base.

Reports for stations falling outside the NMC grid (fig.1) or reports which failed a gross error check (1000 m for heights; 10°C for temperatures) when compared to the analyzed values were rejected. The resulting data base varied from about 400 reports per day at 100 mb to 200 reports per day at 10 mb. Analysis values at stations were obtained from grid point values of 1200 GMT NMC objective analyses by bilinear interpolation.

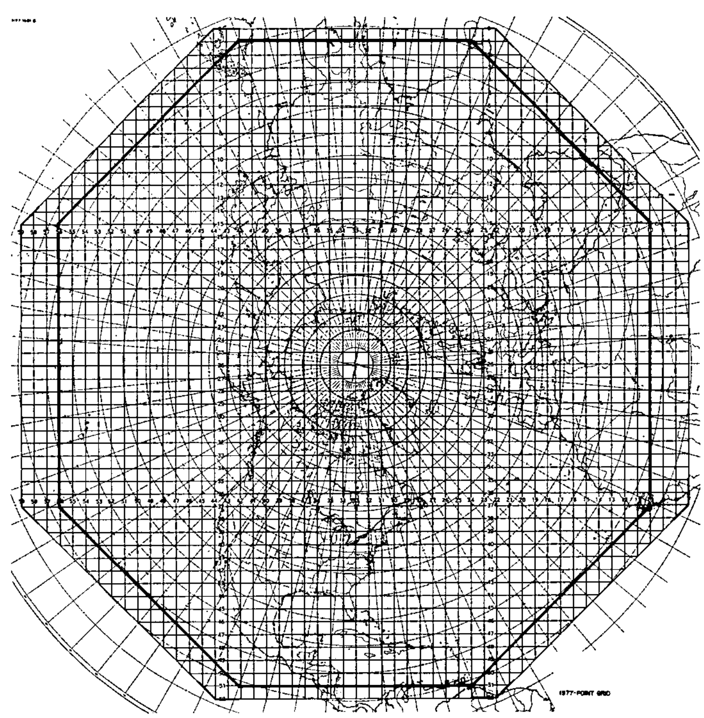

FIGURE 1.—National Meteorological Center 1,977-point grid.

TABLE 1.—*Root-mean-square differences between reported constant-pressure heights (corrected and uncorrected) and analyzed heights for February 1969*

Level	North America			All stations		
	Rms height difference (uncorrected)	Number of observations	Rms height difference (corrected)*	Rms height difference (uncorrected)	Number of observations	Rms height difference (corrected)*
(mb)	(m)		(m)	(m)		(m)
100	32	2, 719	32	52	11, 251	51
50	42	2, 727	39	73	8, 512	65
30	52	2, 577	47	89	7, 387	76
10	100	2, 085	90	155	5, 599	139

*Corrected for radiation effects

TABLE 2.—*Root-mean-square differences between reported temperatures (corrected and uncorrected) and analyzed temperatures for February 1969*

Level	North America			All stations		
	Rms temperature difference (uncorrected)	Number of observations	Rms temperature difference (corrected)*	Rms temperature difference (uncorrected)	Number of observations	Rms temperature difference (corrected)*
(mb)	(°C)		(°C)	(°C)		(°C)
100	1. 0	2, 840	1. 0	1. 2	11, 258	1. 1
50	1. 1	2, 728	1. 1	1. 6	8, 548	1. 4
30	1. 2	2, 606	1. 1	1. 8	7, 439	1. 5
10	3. 0	1, 977	2. 4	3. 1	5, 237	2. 9

*Corrected for radiation effects

Daily and monthly mean differences, rms differences, and mean absolute differences were calculated. These differences were calculated to compare analyzed height and temperature values both with values as reported and with values corrected for the effects of solar and longwave radiation (Finger et al. 1965, McDonnell 1971). For each day of the month, summaries of statistics for each type of radiosonde instrument for North American stations (WMO blocks 70–74), and for all stations were printed out. The same statistical summaries were prepared on a monthly basis and, in addition, summaries for each station were obtained. These have aided in pinpointing certain stations at which reports appear to be consistently different from the analyses.

In addition, a computer routine was developed to plot monthly station statistics on the NMC grid, so that an overall view of difference between reported and analyzed values could be quickly obtained.

3. RESULTS

The 1-mo rms differences are summarized in tables 1 and 2. Table 1 shows that the rms difference between corrected observations and analyses increases from 51 m at 100 mb to 139 m at 10 mb. Over North America, the rms height difference increases from 32 m at 100 mb to 90 m at 10 mb. The effect of the radiation correction scheme is to improve the rms value for all stations by 1 m at 100 mb, 8 m at 50 mb, 13 m at 30 mb, and 16 m at 10 mb. The rms values may be compared with 25 m at 500 mb found by Gandin and Lugina (1969). NMC 500-mb charts for July 1969 indicated an rms difference of about 21 m for all available radiosonde heights; if the 1–2 percent of the observations rejected before or during the analyses were excluded, the rms difference was reduced to about 14 m.

Table 2 shows that the rms temperature difference between corrected observations and analyses increases from 1.1°C at 100 mb to 2.9°C at 10 mb. The radiation correction improves the rms temperature differences by 0.1°–0.3°C at the various levels. Over North America at 10 mb, however, there is a noticeably greater improvement of 0.6°C.

The increase in rms differences with altitude shown in tables 1 and 2 may be related to any of the following causes:

1. A decreasing number of reports with increasing altitude.
2. The use in analysis of offtime observations (not included in the data base for this study).
3. The use of offlevel data extrapolated upward from the termination level of the radiosonde report (at 10 mb, where this problem is most critical, the extrapolation may be from as far below as the 16-mb level).
4. Increasing amounts of data rejected by the analysis system at higher levels.
5. Increasing instrumental variability with height.
6. Smoothing of the analyzed fields.

These effects can be noted in tables 3 and 4. Table 3 is a summary of data utilization at the 50-, 30-, and 10-mb levels on Feb. 11, 1969. Both the total number of reports and the number of ontime reports decrease with

TABLE 3.—*Summary of data utilization for 1200 GMT objective analyses, Feb. 11, 1969*

Level parameter	50 mb		30 mb		10 mb	
	Height	Temp.	Height	Temp.	Height	Temp.
No. of reports:						
In initial data set	415	415	377	377	315	314
On time	295	298	258	264	203	223
Percent on time	71	72	69	70	64	69
Rejected as outside acceptable limits before analysis began*	34	5	36	5	62	22
Remaining for use in analysis	381	410	341	372	253	292
Rejected during analysis	33	6	41	9	50	59
Used for all analysis scans	348	404	300	363	203	233
Rejected as outside acceptable limits after analysis completed*	22	0	17	0	18	0
Within acceptable limits after completion of analysis*	326	404	283	363	185	233
Percent of initial data set	78	97	75	96	59	74

*The acceptable limits are explained in table 4.

TABLE 4.—*Census of stratospheric analysis input data for Dec. 29, 1967*

Category	50 mb		30 mb		10 mb	
	Height	Temp.	Height	Temp.	Height	Temp.
No. of reports						
Onlevel, ontime	310	309	267	266	104	104
Onlevel, offtime	79	80	89	90	80	80
Offlevel, ontime	6	7	8	9	72	72
Offlevel, offtime	2	2	11	13	45	45
	397	398	375	378	301	301

TABLE 5.—*Data limits for objective analysis*

	Height (m)		Temp. (°C)	
	N	S	N	S
Preanalysis scan (Scan 1)	$1.25\|\nabla H\|+50$	$1.25\|\nabla H\|+50$	12	8
Scan 2	160	70	8	6
Scan 3	120	60	5	4
Scan 4	100	50	4	3
Postanalysis scan (Scan 5)	100	100	5	5

Explanation:
If data varies from the value of the field interpolated to the station position by more than the value given in the table, they are rejected from the analysis unless other nearby values (including values inserted by the analyst) also differ from the field value similarly or unless the analyst forces retention of the data. See Finger et al. (1965).

N is the limit for points north of 35°N latitude; S is for points south of 35°N latitude. The field for the preanalysis scan is the "first-guess," which is 50 percent 24-hr persistence and 50 percent regression from the next lower level.

increasing altitude. At higher altitudes, significantly smaller percentages of the data were within acceptable limits (table 5) after analysis.

Various studies of the use of time-merged and vertically extrapolated data have been done by the Upper Air Branch of NMC. The most recent concerned the 50-, 30-, and 10-mb data for the 1200 GMT charts on Dec. 29, 1967. (It is doubtful that any significant improvement in the data base had occurred by February 1969.) These studies are summarized in table 4 which shows that, at 50 mb, 78 percent of the data is onlevel and ontime; at 30 mb, 71 percent is onlevel and ontime; while at 10 mb only 35 percent is in this category. The major reason for the great increase in rms differences at 10 mb is the larger percentage of ontime, lower level data that are extrapolated for the data base. Unfortunately, there was no way to identify these reports and eliminate them from this study.

Further insight into the effect of the analysis system was provided by plotting day-to-day values of the mean differences. Figure 2 shows the graph for 100-mb heights. The anomalous values on February 1, 8, and 15 resulted because the data were reanalyzed using a vorticity amplifier and a heavier smoothing routine on those days. This increases the gradient in areas of cyclonic curvature and decreases it in areas of anticyclonic curvature. The net effect during the winter is to make the analyzed heights lower than reported heights. (As a result of this study, it was suggested that the analyst monitoring the objective analysis would be well advised not to rerun the 100-mb analysis except under unusual circumstances.)

Figure 2 also indicates that there is a bias in the difference between corrected and analyzed heights at

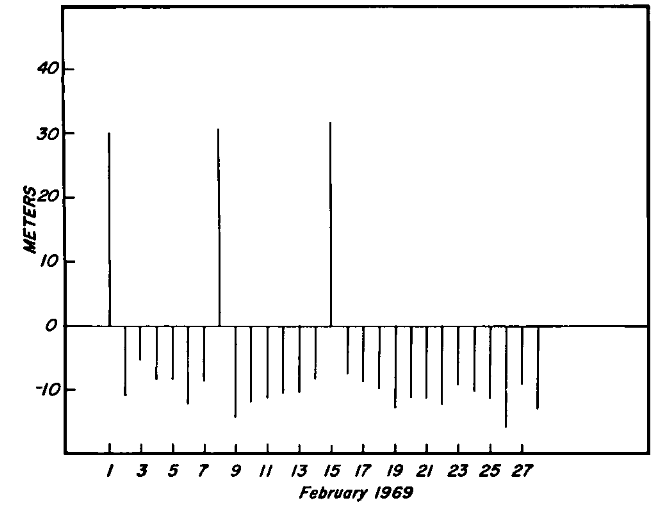

FIGURE 2.—Daily mean height differences at 100 mb for February 1969. [Reported (corrected) heights minus objectively analyzed heights.]

TABLE 6.—*Summary of 50-mb height differences for various instruments (reported heights minus analyzed heights without and with shortwave radiation corrections)*

Instrument type	February 1969 Uncorrected rms difference	Corrected rms difference	Number of reports
	(m)	(m)	
ESSA (External thermistor)	43	40	2, 976
U.S.S.R. (A-22-III & A-22-IV)	90	80	2, 841
U.S. Military (AN-AMT 4)	58	60	853
Vaisala (RS-12; duct type)	90	78	448
Japanese (code sending)	37	(37)	428
Kew (Mark II-B)	104	99	255
Metox	151	86	191
Graw (M.60 & H.50)	30	31	166
Chinese	63	(63)	105
Indian (Fan type & chronometric)	78	(78)	55
Freiberg	107	33	55
Swiss modified	63	(63)	26

Values in parentheses are not corrected, either because no correction scheme is available or because all 1200 GMT observations occurred in darkness.

100 mb, with the analyzed heights being consistently about 10 m higher (in the mean) than the corrected heights. The source of this bias is not known at present, but one suggested explanation is that smoothing dampens the amplitude of features and has the effect of raising the Lows more than lowering the Highs because the former are of shorter wavelength (usually) and more affected by the smoothing (McDonnell 1971).

Table 6 shows a 1-mo summary of 50-mb height differences for various types of instruments. Most instruments used in Europe tend to give the greatest rms differences between reported and analyzed heights. This results from the problems of instrument compatibility discussed by McInturff and Finger (1968).

4. CONCLUSIONS AND OUTLOOK

Rms differences between reported heights (corrected for radiation effects) and objectively analyzed heights at levels of 100 mb and higher during February 1969 are shown to increase from 51 m at 100 mb to 139 m at 10 mb over the NMC Northern Hemisphere grid. These values are noticeably greater that the 25-m rms difference found at 500 mb. Over North America, height differences ranged from 32 m at 100 mb to 90 m at 10 mb. Rms temperature differences for all stations increased from 1.1°C at 100 mb to 2.9°C at 10 mb. For North America, rms values were 1.0°C at 100 mb and 2.4°C at 10 mb. The greater differences outside North America arise from problems of instrument compatibility.

Additional utilization of this information in several ways is planned:

1. The ongoing study of the radiational corrections (McInturff and Finger 1968) will be facilitated through the use of tabulations of monthly station rms differences, because these tabulations indicate the stations at which there are consistently large differences between corrected and analyzed reports. In some cases, these tabulations lead to the discovery of changes in instrument types used.
2. A similar study is projected for a summer month.
3. During May and June of 1969, temperature and height profiles derived from remote atmospheric soundings from the Nimbus 3 satellite became available for use in objective analysis at NMC. A study is underway to ascertain if there is a noticeable change in rms differences following the introduction of this new type of data.
4. Further investigation of the apparent bias in 100-mb height differences is underway.

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